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ECONOMIC EVALUATION OF FORECASTS OF SOCKEYE SALMON *(ONCORHYNCHUS NERKA)* RUNS TO BRISTOL BAY, ALASKA

by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1971

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PREPARATION OF THIS PAPER

Forecasting of fish distribution or abundance from oceanographic or other studies is becoming technically feasible for an increasing number of fisheries throughout the world, but the economic justification for such work has on occasion been called in question.

This paper, by Dr. S.B. Mathews of the State of Washington Department of Fisheries, describes the assessment of the economic value of forecasts of salmon runs in one part of the North Pacific. It shows that, up to a certain level, the costs of forecasting are more than repaid by increased profits to the fishery, but that the costs of a very accurate forecast cannot be recovered by the fishery.

The Fishery Economics and Institutions Division of the Department of Fisheries is issuing this study in the expectation that the results achieved and the techniques used will be of very wide general interest when considering the justification of developing forecasting systems in other parts of the world.

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ABSTRACT

Several fisheries agencies operating in Alaska spend an aggregate of $100 000-$250 000 yearly to forecast the sockeye salmon (Oncorhynchus nerka, Walbaum) runs to Bristol Bay. Accurate forecasts of this widely varying run allow the salmon canning industry to plan efficient yearly scales of operation. Also, accurate forecasts, particularly of the runs to the separate rivers of Bristol Bay, should increase the productivity of the runs by enabling management for optimum escapement. To measure the potential economic value to the canning industry of accurate forecasts, a computer model of the fishery and the canning industry was written and used to simulate performance over 100-year periods:

1. To simulate the runs to the eight major rivers, spawner-return relationships of the Ricker type were fitted to the data for all rivers except the Kvichak. For the highly cyclic Kvichak, the population controlling mechanism was based on a postulated interaction between successive year classes. Random error terms and age class percentages were estimated for each stock and used to produce appropriate variability and age composition of the total runs.

2. To simulate the removal of immature fish by the Japanese high-seas fishery, a multiple regression equation was fitted to the data on immature fish at sea. To simulate removal of mature fish, a relationship between ocean-age composition of the run and high-seas fishing rate was used.

3. To simulate an inshore fishery without river-system forecasts, linear relationships between ocean-age composition and fishing rates for individual rivers were established. To simulate an inshore fishery with accurate river-system forecasts, the fishing rates were based on optimum escapements determined from spawner-return relationships.

4. To simulate the operation of the canning industry, its costs, productive capacity and organization were determined. Decision rules for investment in canning facilities, which depended on forecasts policies, were included. The measure of economic performance was the seasonal operating margin of the canning industry, defined as the difference between receipts from canned fish sales and total operating costs.

With a forecast of the entire run which guided the pre-season investment by the canning industry but was not useful in optimum management, the operating margin averaged about $500 000 to $600 000 more than with no forecast, depending on the accuracy of the forecast. With forecasts to each river which enabled both efficient pre-season investment and optimum management of the fishery, the operating margin averaged approximately $2 500 000 more than with no forecasts, but the results were dependent on highly theoretical optimum management assumptions for the Kvichak.

A moderately accurate forecast provided benefits almost as great as a highly accurate forecast. In view of the much greater cost for a highly accurate forecast, optimum investment in a forecasting programme might be that which gives only a moderate level of accuracy.

It was concluded that the benefits to the canning industry from forecasting would likely be dissipated in higher raw fish costs if profits were reasonable without accurate forecasts. Higher fish prices with free entry of fishing gear would attract more but superfluous gear which would negate any net economic gain from forecasting.

In order for forecasts to provide their greatest yield to the fishery where net yield is the total profit to the canning industry and the fishing fleet, the fleet would need to be greatly reduced. In the simulation model, a fleet of 350 boats was optimal. With this small-sized fleet, an accurate forecast of the total run added $1 200 000 to net yield, and accurate river-system forecasts about $5 000 000.

INTRODUCTION

Accurate forecasts of the highly variable runs of commercially exploited salmon (Oncorhynchus sp.) have long been recognized as desirable by management agencies, fishermen, and processors. Since 1960, the Bureau of Commercial Fisheries of the U.S. Fish and Wildlife Service, the Fisheries Research Institute of the University of Washington, and the Alaska Department of Fish and Game have issued annual forecasts of the valuable runs of sockeye salmon (O. nerka) to Bristol Bay, Alaska. These forecasts are averages derived from several techniques; they are moderately accurate but have cost annually from $100 000 to $250 000 depending on the amount of effort put forth. Table 1 compares the forecasts of the total Bristol Bay run to the runs themselves. Separate forecasts are also made for each of the 11 major sockeye rivers of Bristol Bay, which have been, generally speaking, less accurate than the forecasts of the total run. Ossiander (1966) describes the forecasting techniques.

Accurate forecasts of the total run allow the geographically remote salmon canning industry to gear up precisely for each year's run, being, therefore, neither underprepared for a large or overprepared for a small run. Accurate forecasts for each river would increase the chances of attaining optimum escapements and thus increase the long-term yields. To evaluate these potential benefits, a model of the fishery and associated canning industry was developed, which was used to simulate performance over 100-year periods under a variety of forecast assumptions.

The fishery sector of the model was based on historical information through 1965 on size and age composition of the runs, spawning escapements, catch rates, and seasonal distribution of the catches. The industry sector was based on information on costs, production, and price furnished by several of the major canneries. The model which contained about 1 300 equations was written in DYNAMO (DYNAmic MOdels), a language designed for the simulation of industrial management problems (Pugh, 1963). It is described in detail and listed by Mathews (1967). The present paper presents only a summary description and the major results from experiments with the model.

Specifically, the model was designed to estimate: (1) the potential increases in canning industry profits from maximal efficiency in year-to-year scales of operation provided by accurate forecasts of the total run; (2) the potential increases in canning industry profits from optimum management of the runs; (3) the potential increases in net economic return to the fishermen from increased cannery efficiency and increased physical yields; and (4) the increase in net economic yield (the sum of cannery profits and net returns to the fishermen) from the Bristol Bay fishery under conditions of highly accurate forecasts, precise management, and a smaller but more nearly optimum-sized fishing fleet.

Table 1. Total Bristol Bay runs and forecasts of the runs, 1960-67

Year	Total run[1/] (millions of fish)	Forecast of run (millions of fish)
1960	42.6	35.0
1961	26.3	27.0
1962	12.3	9.7
1963	8.6	15.6
1964	13.4	17.7
1965	64.0	27.8
1966	32.7	20.6
1967	15.7	12.3

1/ The total run includes inshore catches and spawning escapements as well as Japanese catches from the mature runs and catches of immature fish in the year before maturation.

THE FISHERY

Ninety per cent of the value of the salmon caught and processed from Bristol Bay is from the sockeye runs to 11 proximally located rivers (Figure 1). The total inshore catch has ranged from 3 to 25 million sockeye salmon since 1921, providing a canned pack of from 200 000 to 1 500 000 cases valued at from $7 million to $57 million wholesale.

The cyclic Kvichak River run is the most important single one, having exceeded 50 million sockeye salmon (catch plus spawning escapement). Several of the other systems have runs of from 1 to 3 million sockeye salmon. All runs arrive almost simultaneously and pass through the fishery rapidly.

The bulk of the catch is made within the first 2 weeks of July. Most of it is canned in the 11 operating canneries (Figure 1) with only a small portion hauled elsewhere in freezer ships and chilled-brine scows. Since the fish cannot be held more than a few days before canning, and since the area is so far from labour and supply sources, it is exceedingly important that the industry be properly geared up before the season.

The inshore fishery is entirely by gill nets and operates only in the esturial areas (Figure 2) as the fish pass through on their spawning migration; stationary nets are fished from the shore and drift nets are fished from one-or two-man powered boats. The drift net fleet, which takes most of the catch, numbers about 2 000 vessels. A consequence of the use of size-selective gill nets is that the fishing rate tends to be higher on the larger 3-year-at-sea fish than for those that spend 2 years at sea. Thus, in absence of accurate river system forecasts, the inshore fishery rates on most runs have tended to depend upon the ocean age composition of the runs (Figure 2).

Most operations in the canneries are mechanized and standardized; the machinery has changed little since its description by Freeman (1935). The unit of production is the can line, the continuous series of operations which lead from the cleaned, whole fish to the vacuum-canned, cooked, and packaged product. The standard line in Bristol Bay is the 1-lb line, but a fair portion of the sockeye salmon catch (particularly since about 1960) is processed in $\frac{1}{2}$-lb, and to a lesser extent, $\frac{1}{4}$-lb cans (Table 2).

Transportation of fish in chilled-brine scows, begun recently in Bristol Bay, allows a cannery on a particular river to obtain fish from other areas as well. This enables the pooling of canning and transporting facilities among canneries on different rivers and has led to consolidation within the industry to the point where three companies control most of the operations.

THE MODEL

The major elements of the model were the runs to the eight major rivers of Bristol Bay, a Japanese high-seas fishery on immature and mature Bristol Bay sockeye salmon, an inshore fishery with a triangular probability distribution to describe the seasonal availability of the fish to the fishery, and a canning industry consisting of three consolidations of four canneries each. A fleet of fishing boats with specified costs of operation and fishing power was later added after evaluating the benefits of forecasting to the canning industry alone. The salmon populations, except for the Kvichak River run, were controlled by Ricker-type (Ricker, 1958) spawner recruit relations estimated from existing data:

$$R = aSe^{-bS+Z}$$

Where R was the total number of returning adults of ages 4, 5, and 6 produced from a spawning escapement of S fish; a and b were parameters estimated for the specific population; Z was a normal random deviate with mean zero and standard deviation so specified for each population as to produce random variability within the approximate range observed.

The cyclic behaviour of the Kvichak River run, as with other cyclic salmon populations, is not understood, although it has been studied (e.g. Donaldson, 1966). However, the model in keeping with reality had to produce such a cyclic run since this is a very important aspect of forecast evaluation; i.e., the Kvichak cycle, even though it has historically shifted period back and forth between 4 and 5 years, provides something for industry to gear its planning to even with no forecast.

It was desired to have a simple, but biologically plausible relationship, which would produce a cyclic Kvichak run that would shift in period as does the actual run. An interactive relationship among year classes was postulated:

$$R = cS_i e^{-d_1 S_i - d_2 S_{i-1} - d_3 S_{i-2} + Z}$$

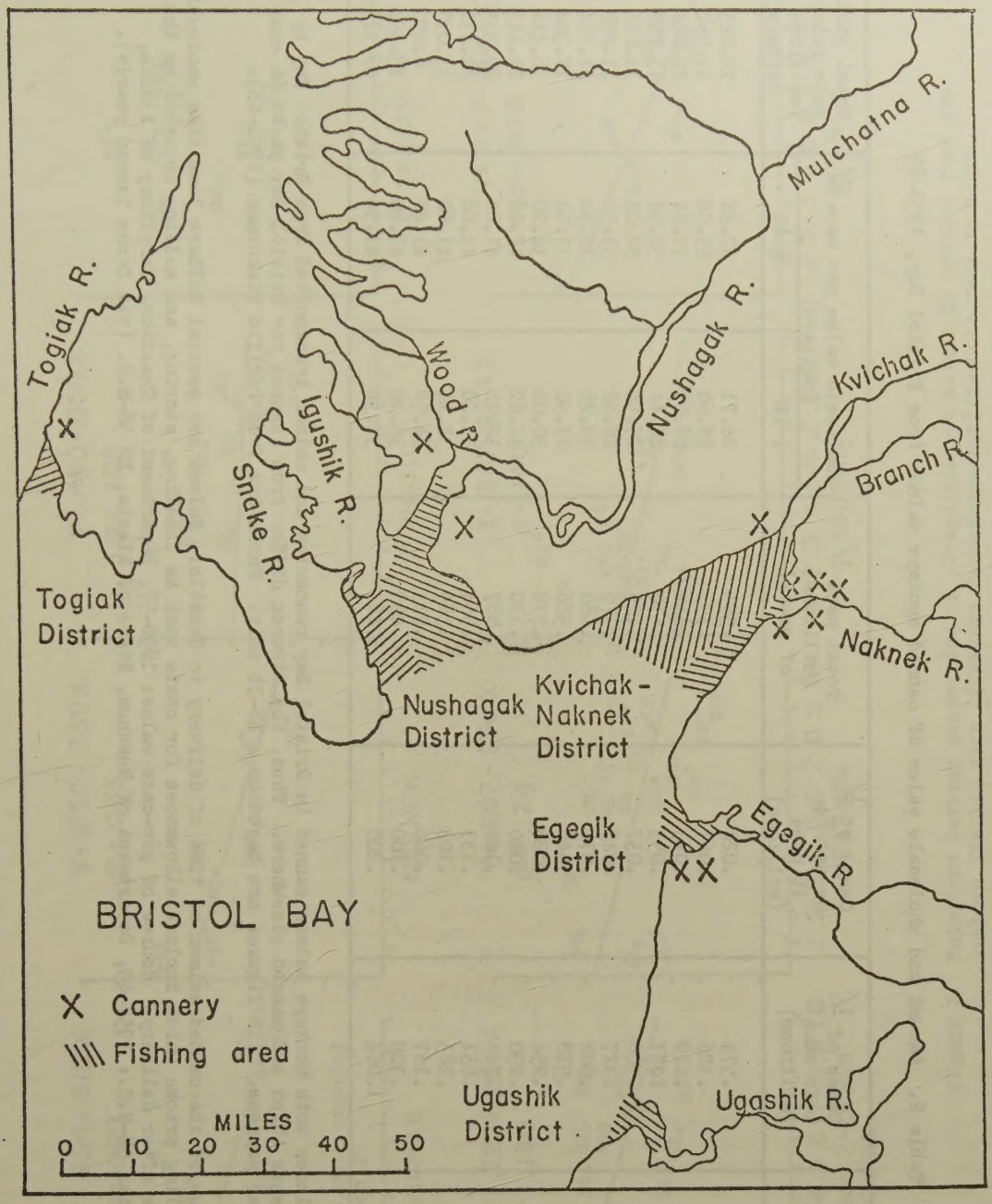

Figure 1. Rivers, fishing districts, and location of operating canneries in Bristol Bay, Alaska

Table 2. Amount and wholesale value of canned sockeye salmon from Bristol Bay, 1950–65

Year	Cases of 1/ 1-lb cans (millions)	Cases of 1/ ½- and ¼-lb cans (millions)	Total pack 1/ (millions of cases)	Wholesale value per case 2/ (dollars)		Total wholesale value (millions of dollars)
				1 lb	½ lb	
1950	.571	.024	.595	26.71	32.26	16.025
1951	.326	.067	.393	28.60	33.86	11.592
1952	.819	.023	.842	26.07	31.84	22.084
1953	.477	.053	.530	24.44	30.94	13.298
1954	.388	.037	.425	25.58	30.04	11.036
1955	.327	.049	.376	28.82	33.58	11.070
1956	.602	.078	.680	30.28	38.92	21.264
1957	.518	.048	.566	29.90	37.84	17.304
1958	.254	.024	.278	30.02	34.20	8.446
1959	.290	.040	.330	32.62	42.08	11.143
1960	.743	.144	.887	32.18	41.84	29.935
1961	.831	.133	.964	31.20	41.68	31.471
1962	.283	.103	.386	31.14	41.60	13.097
1963	.167	.066	.233	34.52	41.40	8.497
1964	.309	.100	.409	36.28	42.80	15.490
1965	1.264	.200	1.464	32.36	41.36	49.175

1/ Includes both sockeye salmon canned in Bristol Bay canneries and salmon transported from Bristol Bay by freezer ships and canned elsewhere. Thus, the figures differ from figures for Bristol Bay packs in some other sources. All figures are based on a 48-lb unit. Packs are from Pacific Fisherman (1951-66).

2/ Value of the canned salmon at time of delivery to Seattle. Values are several dollars less than wholesale selling prices which include allowances for costs such as labelling, storing, and selling incurred on the pack after delivery. Source of per-case value: 1950-57, Department of Taxation, Territory of Alaska, deptax 58-S.C.: 1958-65, Department of Revenue, State of Alaska, DR 58-S.C. (tax forms issued yearly).

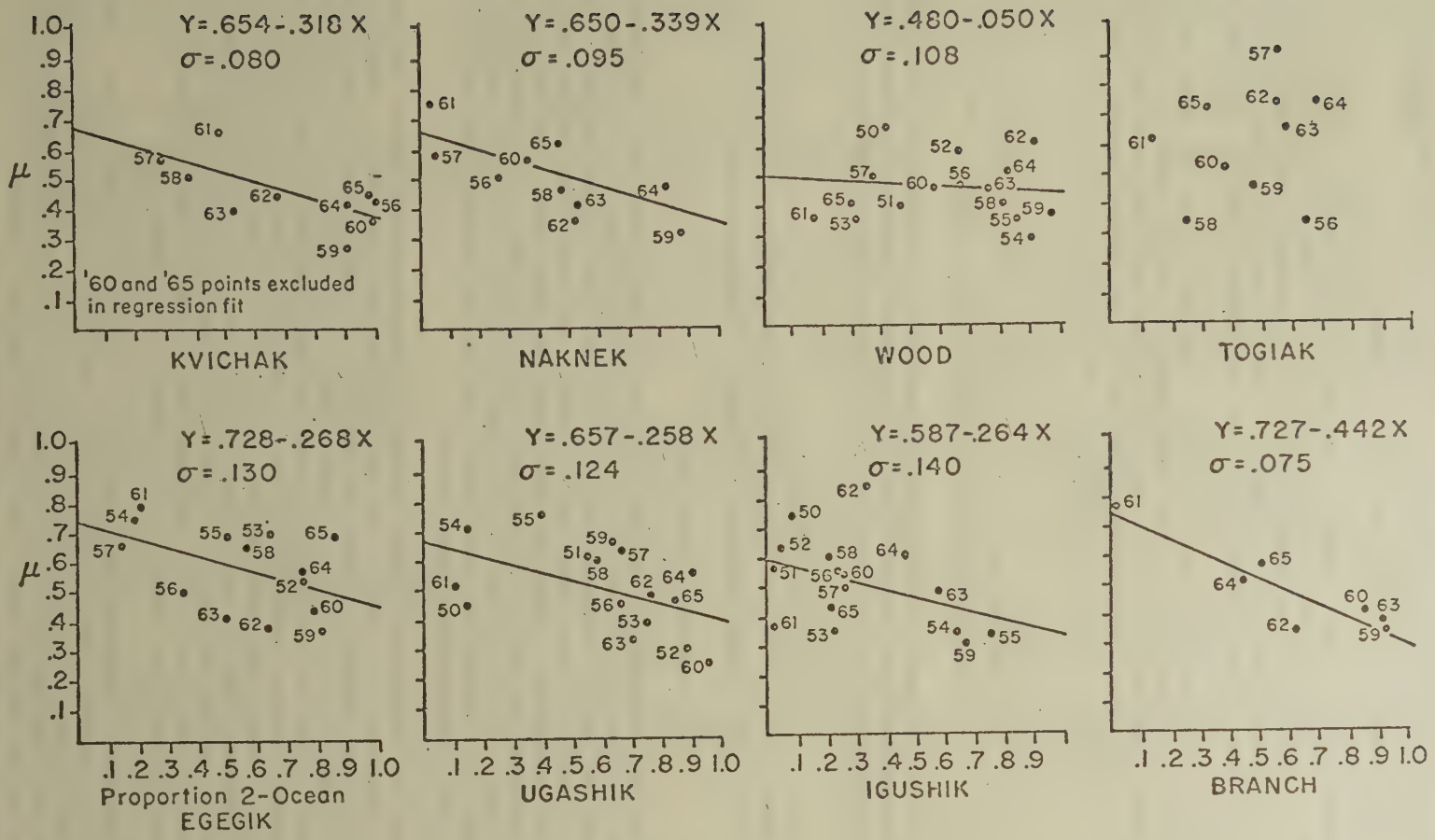

Figure 2. Relations between proportion of .2-age sockeye salmon in inshore runs and inshore fishing rate ([inshore run-escapement]/inshore run) in major Bristol Bay rivers

Where R was the total return of ages 4, 5, and 6 from S_i spawners in year i; S_{i-1} and S_{i-2} were the numbers of spawners in years i-1 and i-2; $\underline{c}$, $\underline{d}_1$, $\underline{d}_2$, and $\underline{d}_3$ were parameters; and Z was normal $(0, \sigma)$. A least-squares solution for the parameters from the limited data (7 years) did not give reasonable values. Hence, arbitrary choices of these as well as σ were made in order to produce Kvichak runs of appropriate size, variability, and periodicity (Figure 3). Basically, the population cycled with a 4-year period, occasionally shifting to 5 years.

The total returns to each river system were computed by the model and segregated into the four major age classes, 1.2, 2.2, 1.3, and 2.3 (4_2, 5_3, 5_2, 6_3) according to the relationships specific to river system and based on existing age composition data. Segregated returns were stored for eventual retrieval in the appropriate year. Further random variability was introduced at this point, in that the mode of allocation of the total return to the four age classes depended on normal random deviates.

From each total run, a Japanese high-seas catch of immature 2-ocean-age fish was removed the year prior to the run, and a high-seas catch of matures immediately before inshore arrival. The high-seas fishing rate on mature fish depended on the percent of 2-ocean-age fish in the mature run according to a relation which led quite well through 1965 (though not so well since, personal communication, Mr. R.A. Fredin, U.S. Bureau of Commercial Fisheries, Seattle):

$$M = \frac{1}{a+bP}$$

M = fishing rate

P = percent 2-ocean-age sockeye in total run

The high-seas catch of immature sockeye salmon depended on the abundance of 2-ocean-age immatures and the catch of mature fish made that same year (if the catch of matures is large, the catch of immatures taken later in the summer was usually relatively small since quotas had been largely filled):

$$C = a+b_1X_1 - b_2X_2$$

where C = total catch of immature 2-ocean-age fish

X_1 = total population of immature 2-ocean-age fish

X_2 = catch of mature fish

The inshore harvest operated as follows: Preliminary fishing rates were established which were (1) dependent upon the ocean age composition of the runs if no forecast or only a forecast of the total run was specified, and (2) dependent upon the forecasts and optimum escapement levels for each run, if separate forecasts for each river were specified. For the Kvichak relationship, the optimum escapement level was determined by trial and error with the total model. It should be stressed that this escapement value may have had little real-world bearing because of the unknown cyclic mechanism of the Kvichak run and the arbitrary choice of a population controlling relationship for the model. For the other rivers, the optimum escapement levels were the well-known points where the slope of the ascending limit of the spawner-recruit curve was 45°.

On the basis of the preliminary rates, a quantity termed "available catch" was computed and converted to cases according to a relation between fish per case and ocean-age composition of the run. This quantity of fish so converted was made available to the canning industry over the approximately 20-36 day season allowed in the model (the length of the season in the model varied randomly in keeping with reality - some runs are available only a short time while others delay longer in the fishery). A triangular seasonal pattern of availability was assumed. The actual catch depended upon the quantity of fish "available" in short time intervals, the amount of can lines prepared to operate, and the limitations on the amount of output per line per unit of time. If the "available catch" could not be entirely processed by the industry due to a large run, a sharply peaked run (in time), or both, combined with inadequate canning facilities, the excess was converted back to numbers of fish and apportioned appropriately to each river where it contributed to the escapements.

The cannery segment of the model consisted of three identical consolidations. Each had four canneries - two 4-line canneries and two 2-line canneries. Each of the 4-line canneries had one ½-lb and three 1-lb lines of machinery, and living facilities for four complete crews. Each of the 2-line canneries had two 1-lb lines and one ½-lb line, but it was a 2-line cannery in the sense that it had living facilities for two complete crews, which could be shifted between a 1-lb line and the ½-lb line. At the maximum level of productivity, each consolidation could run a total of six 1-lb lines and two ½-lb lines in its 4-line canneries and a total of four 1-lb lines in its two smaller ones.

Table 3. Summary of costs for an "average" Bristol Bay cannery operating two can-lines 1/

Sunk operating cost	Fishing costs	Variable operating costs
Total - $375 000	Total - $100 000	Pack proportional costs
Items included in total 1. Base wages, including employer-paid benefits and some basic overtime for can-line workers, machinist, carpenters, mess-house crews (portion of wages), tender crews, and miscellaneous employees 2. Food, living, and travel expenses for employees in Item (1) 3. Portion of fuel for power generation, heating, cooking, and operation of tenders, trucks and tractors. 4. Freight north of fuel, food and canning supplies 5. Portion of repair parts and supplies for docks and buildings 6. Tender parts 7. Administrative and office expense 8. Interest to finance season's operation 9. Tender charters, leases, and licenses for misc. vehicles 10. Hospital expenses	Items included in total 1. "Run money" and employer-paid benefits for company fishermen 2. Food, living, and travel expenses for company fishermen and other employees associated with the fishing operation 3. Fishing boat fuel, repair parts, and expendable supplies 4. Base wages for misc. shore workers associated with the fishing operation (including portion of mess-house crews) 5. Portion of fuel for heating and power generation	Costs per case of fish - $13.24 Other costs per case ½-lb case - 6.79 1-lb case - 4.90 Total costs per case ½-lb case - 20.03 1-lb case - 18.14 Items included in other costs per case 1. cans, cartons, salt, glue 2. freight or pack 3. "lay" wage payments 4. handling at docks 5. fuel for power generation 6. fuel for tender operation 7. repair parts for cannery machinery 8. insurance on pack 9. miscellaneous expendable canning supplies Overtime costs per case packed on overtime ½-lb case $ 1.25 1-lb case 2.50

1/ This table represents a consolidation of a large volume of data furnished by the canneries, which varied in form of presentation from cannery to cannery. Allocations of stated costs into the broad categories defined were often arbitrary.

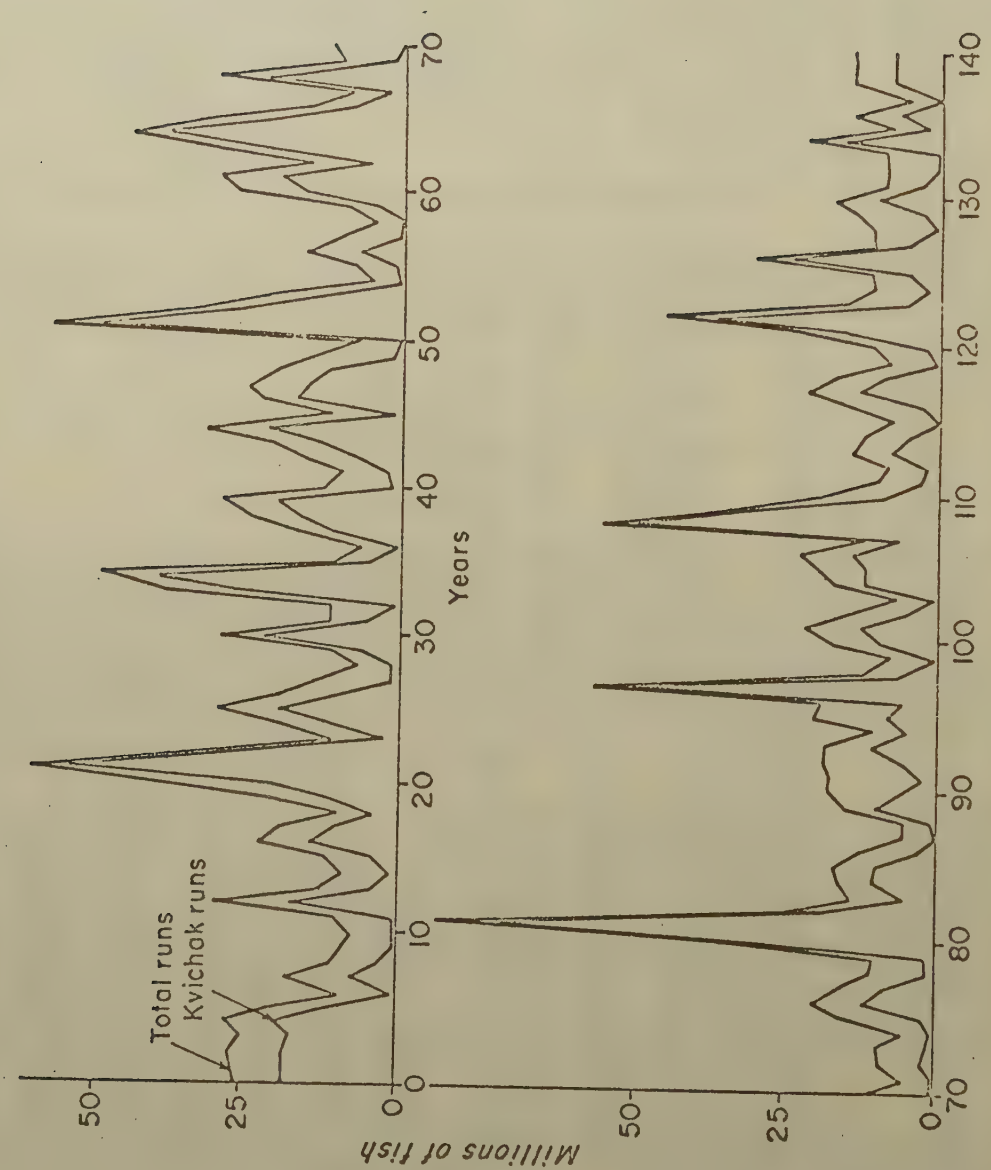

Figure 3. 140 years of simulated Kvichak inshore runs and total Bristol Bay inshore runs

Each consolidation had various levels of preseason preparation up to maximum productivity to choose from, the level depending upon the forecast of the entire run if this was specified or upon the 4-year Kvichak cycle if no forecast was specified. It was assumed that crews could be shifted back and forth between 1-lb and ½-lb lines. Thus, the model operated so that early in the season and late in the season when relatively small quantities of fish were available, or when there was a smaller run than anticipated, the ½-lb lines would be used extensively. This is how the industry actually operates, due to a greater margin on ½-lb cases than on 1-lb cases. When more fish were available than the ½-lb lines could handle, the model assumed that the crews would be used on the 1-lb lines.

In addition to fish which could be packed with the canning facilities readied before the season, the model (in keeping with reality) allowed extra output from lines opened on an emergency basis during the season. A set of decision rules was included in the model which allowed a consolidation at specific intervals during the season to compare its actual pack with what was available to it. A limited number of emergency lines could be added, after 3-day lags to account for the time to get the extra lines operating, on the basis of specified relations between available fish and actual pack up to specified times during the season.

The three major categories of canning costs in the model were sunk costs, fishing costs, and variable operating costs (Table 3). Sunk costs are the expenditures made and financial obligations incurred before the season to prepare the industry for some level of productive capacity. Obviously, the output during a season is dependent upon the amount of sunk costs. The levels of capacity which could be chosen by each consolidation in the model and the sunk costs associated with each level are shown in Figure 4. Fishing costs were assumed to be equal for each cannery and invariant from year to year since the numbers of fishermen and vessels employed by the industry do not seem to fluctuate with expected run size. Most of the variable operating costs, raw fish being the most important single item within this category, were assumed to be directly proportional to pack. The only exceptions were costs for overtime labour, which were computed in the event that the industry required more than 8 hours to pack the fish available to it in any day.

Some of the costs of running a salmon canning company were not included in the model since they do not depend, in the short run, on planned or actual output and would not, therefore, be affected one way or the other by a forecast. These include the fixed costs of owning a cannery (for example, depreciation on buildings and equipment, fire insurance, and home office expenses) and the costs incurred on the pack after it reaches Seattle (for example, labelling, storing, and marketing).

An analysis of wholesale price and output of canned salmon from Bristol Bay indicated that price per 1-lb case was negatively dependent upon the size of the 1-lb pack during the season and the previous year's pack. The price per 1-lb pack, therefore, varied from year to year in the model according to a simple relationship:

$$Y = a - b_1X_1 - b_2X_2$$

Y = price per 1-lb case

X_1 = season's pack

X_2 = previous season's pack

Both output and price of ½-lb cases from Bristol Bay had been relatively invariant, and a constant price was therefore assumed in the model.

The summary statistic which was the basis for comparing economic performance of the industry in experiments with different forecast and management policies, was the seasonal operating margin. This was the difference between total wholesale value of the pack and the costs explicit in the model. For evaluating the consequences of forecasting to the canning industry, the average operating margin provided as good a summary statistic as profit. Differences in operating margins with different forecast policies reflected absolute differences in potential profits (or losses). On the other hand, a positive operating margin did not necessarily imply a positive profit due to the fact that fixed costs of cannery operation were excluded from the model.

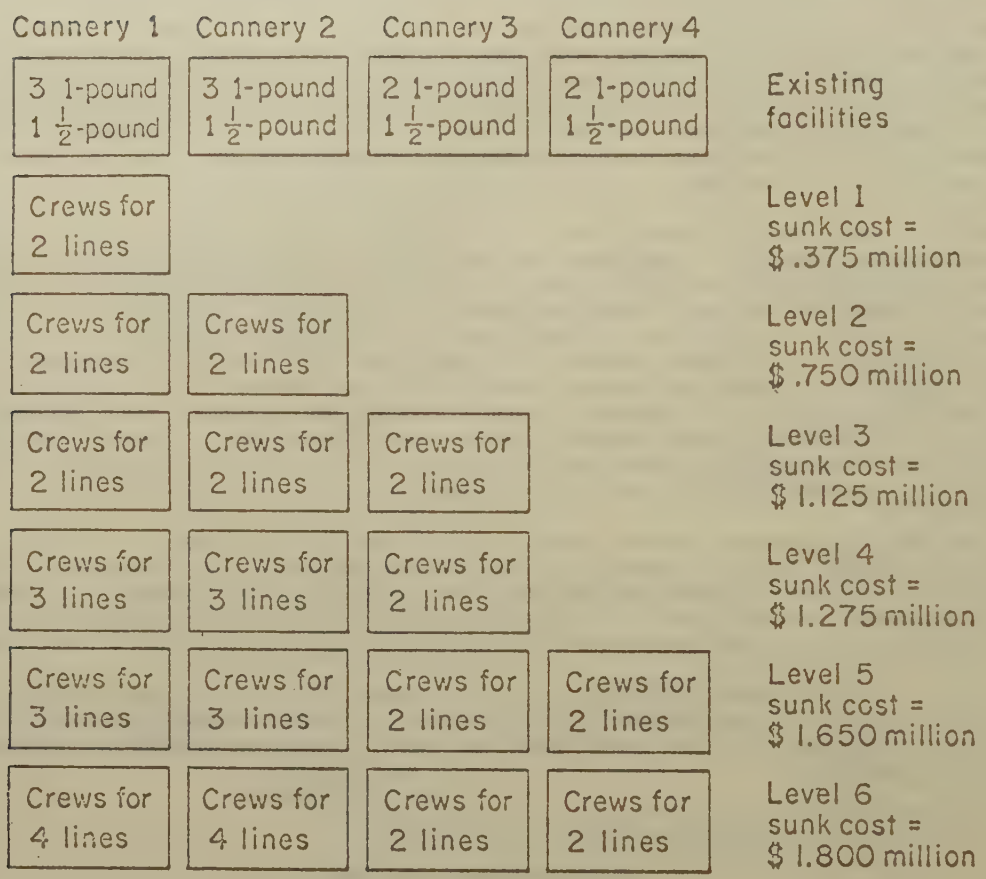
Cannery 1
Cannery 2
Cannery 3
Cannery 4
3 1-pound 1 ½-pound
3 1-pound 1 ½-pound
2 1-pound 1 ½-pound
2 1-pound 1 ½-pound
Existing facilities
Crews for 2 lines
Level 1 sunk cost = $ .375 million
Crews for 2 lines
Crews for 2 lines
Level 2 sunk cost = $ .750 million
Crews for 2 lines
Crews for 2 lines
Crews for 2 lines
Level 3 sunk cost = $ 1.125 million
Crews for 3 lines
Crews for 3 lines
Crews for 2 lines
Level 4 sunk cost = $ 1.275 million
Crews for 3 lines
Crews for 3 lines
Crews for 2 lines
Crews for 2 lines
Level 5 sunk cost = $ 1.650 million
Crews for 4 lines
Crews for 4 lines
Crews for 2 lines
Crews for 2 lines
Level 6 sunk cost = $ 1.800 million

Figure 4. Six levels of preseason preparation for each of the three canning consolidations in the Bristol Bay simulation model

RESULT AND DISCUSSION

After some initial comparisons to confirm that the output from the model conformed reasonably well to the fishery itself (Table 4; Figure 5), a series of experiments were conducted to determine the maximum operating margin of the canning industry with no forecast available.

The best strategy for the industry to follow, without a forecast, was to invest each year in sunk costs at the level which would provide the maximum operating margin for the size of run which had occurred 4 years previous.[1/] This was a favourable strategy since the Kvichak population in the model cycled with a predominantly 4-year periodicity. The operating margin averaged $4 620 000 with packs averaging 565 000 cases.

After establishing the greatest expected margin with no forecast, the model was run with several forecast policies. First, it was assumed that the only forecast available was for the total inshore run. Industry was assumed to invest in sunk costs each year at the optimum level (to maximize operating margin) for the size of the run expected from the forecast. But, it was assumed that optimum fishery management would not be possible with only a forecast of the entire run. In actuality, a forecast of the entire Bristol Bay run does allow some basis for management precision of individual streams. However, assuming otherwise, made it possible to separate the benefits to the industry from forecasting into those due to efficient year-to-year scales of canning preparation and those due to optimum management of the runs.

Two levels of forecast accuracy were evaluated, one yielding forecasts which ranged in possible error up to ±50% of the runs (either entire run or separate runs depending on the forecast policy specified) and the other yielding forecasts with error ranging to ±10% of the runs. The average packs and operating margins with these several forecast policies are shown below:

	Pack (millions of cases)	Operating margin (millions of $)
Forecast of entire run		
±50% accuracy	.635	5.230
±10% accuracy	.647	5.353
Forecasts of runs to separate rivers		
±50% accuracy	.723	6.722
±10% accuracy	.864	6.977

A forecast of the entire run with error ranging to ±50% of the actual run provided an average increase in operating margin over the non-forecast policy of over $500 000 per year. This level of accuracy is currently being achieved. Increasing the accuracy to a level of error of ±10% added only about $100 000 to average operating margin. Although precise price tags cannot be placed on each level of forecast accuracy, these results imply that while forecasting clearly adds benefits well in excess of its costs, the incremental benefits in going from a moderately accurate level of forecasting, ±50% error range, to one of greater accuracy, ±10% error range, might not be worth the additional cost required. For example, the present high seas sampling techniques will give forecasts of the total run within the ±50% error range for a cost of roughly $100 000 per year. To attain the higher degree of accuracy would cost perhaps $250 000 at a minimum. The additional $150 000 would add less than this amount to the average operating margin. It is obvious that there is an optimal level of accuracy for which to design a forecast programme, wherein incremental benefits in going to a greater level of accuracy are less than the incremental forecasting costs. The higher accuracy would simply not be worth the additional cost. The ±50% error range may be quite close to such an optimum for the Bristol Bay run. Forecasts of the separate runs, even with only moderate accuracy of ±50% (such accuracy for individual runs has not yet been achieved) would potentially add an additional $1 500 000 to the cannery profits if used as a basis for optimum fishery management. This latter figure is dependent to a large measure upon the assumptions developed regarding the important Kvichak stock. Although it is

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1/ Separate runs or "replicates" could be made by allowing different sequences of values for the random deviates. However, for experiments covering 100 years of simulated runs, average operating margins differed little between replicates compared to differences in operating margins between different forecast policies. The standard technique for each policy tested was to run the model three times for 100-year periods, compute the 100-year mean for each important variable, and take the mean of the three 100-year means.

Table 4. Means and ranges of actual Bristol Bay sockeye salmon production and simulated production with a forecast of the total run only (Runs, catches, and escapements are in millions of fish; packs in millions of 48-lb cases; value in millions of dollars)

	Actual output			Simulated output	
	Years	Mean	Range	Mean	Range
Inshore runs					
Ivichak	1956-65	10.501	.560-42.517	11.107	.138-67.814
Naknek	1956-65	1.905	.527- 3.533	2.096	.747- 4.541
Egegik	1952-65	2.232	.740- 4.716	1.975	.617- 4.388
Wood	1950-65	1.418	.540- 3.488	1.388	.338- 3.399
Ugashik	1948-65	1.176	.318- 3.047	1.011	.186- 5.891
Branch	1959-65	.719	.133- 2.066	.780	.141- 2.911
Igushik	1950-65	.408	.091- 1.046	.445	.097- 1.401
Togiak	1956-65	.307	.111- .397	.318	.099- 1.401
Total	1956-65	18.908	5.704-53.508	19.114	5.787-74.426
Inshore catch	1956-65	8.628	2.871-24.729	8.347	.252-30.151
Japanese mature catch	1956-65	3.203	.614- 7.660	2.681	.509-10.447
Japanese immature catch	1956-65	.845	.062- 2.075	.778	.000- 2.914
Total escapement[1/]	1956-65	10.056	2.573-28.163	10.767	2.508-46.149
Inshore pack					
½- and ¼-lb	1956-65	.094	.024 .200	.157	.019- .353
1-lb	1956-65	.526	.167- 1.264	.473	.086- 1.624
Total	1956-65	.620	.233- 1.464	.630	.182- 1.882
Inshore pack wholesale Value	1956-65	20.582	8.446-49.175	21.956	7.153-56.844
Percentage of 2 ocean-age fish in inshore run	1956-65	66.79	35.92 -93.08	68.34	26.51 -97.74

1/ These escapements include only the eight streams in the model, which provide about 98 percent of the total run and catch in Bristol Bay

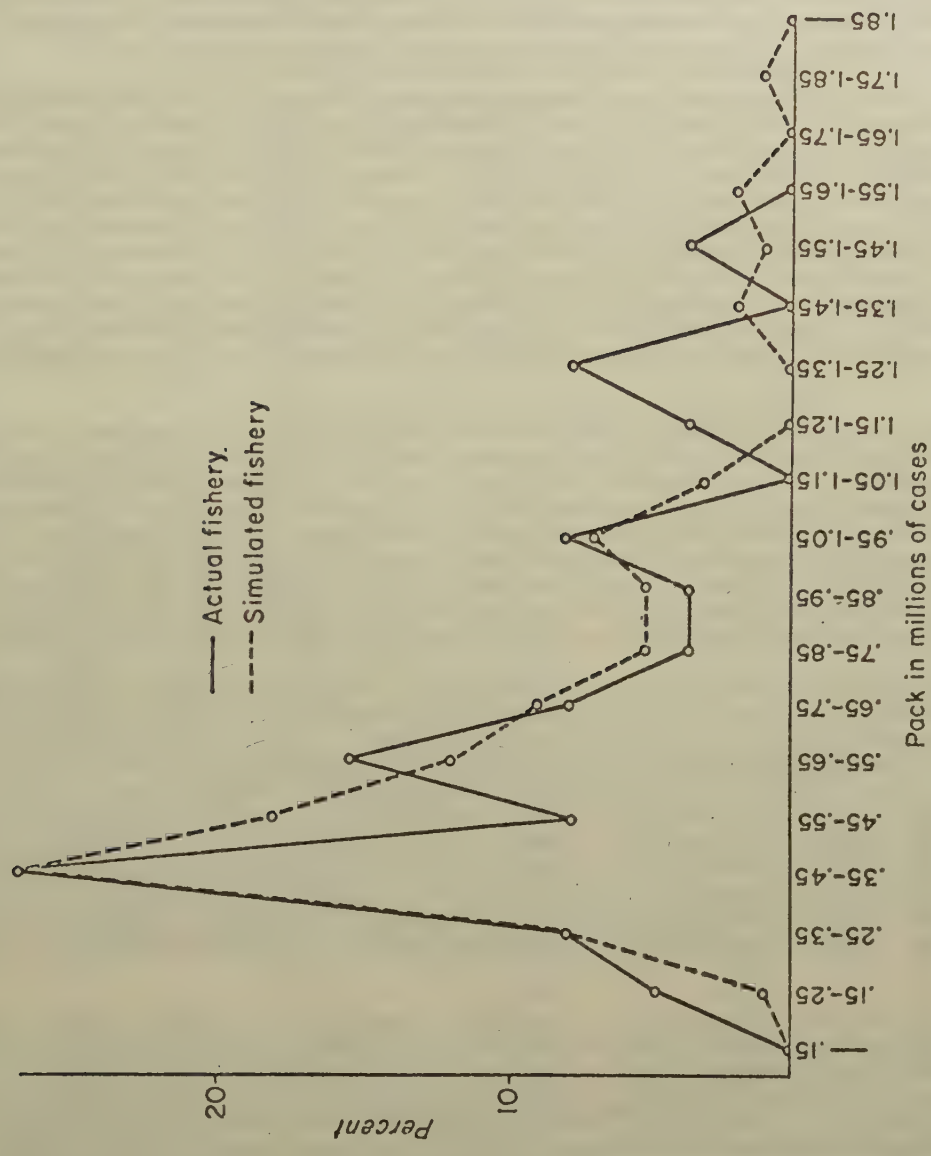

Figure 5. Frequency distributions of total Bristol Bay pack from 100 years' simulated runs and from the actual runs since 1940. Pack data from Pacific Fisherman, 1951-66

yet unknown, some optimum management strategy must exist for this stock and an accurate Kvichak forecast would be essential in applying this strategy. The significant result from these experiments was that although a forecast of the total run is potentially worth several times the cost of making one, in terms of increasing efficiency of cannery preparations before the season, far greater benefits lie in the increased physical yields resulting from accurate forecasts for each stock.

These benefits from forecasting may not necessarily be realized entirely by the canning industry as addition to profits. If the industry was making profits comparable to similarly risky investments before the forecasts became available, then competition within the industry for raw fish, cannery labour, and markets as profits tended to rise from forecasting might (1) move the price of the canned product downward, (2) force the raw fish price paid to fishermen upward, or (3) move the costs of other factors of production such as cannery labour upwards. Thus, consumers, fishermen, and cannery labourers stand to benefit from accurate forecasts as well as cannery investors.

However, if through existing but unpredictable economic forces, most of the benefits are merely passed on to the fishing sector through a rise in raw fish prices (as is not unlikely), a lasting net economic gain would be improbable under the existing system of unlimited entry of fishermen and fishing gear. The rise in fish prices would only serve to attract more units of gear to the fishery which would be completely unnecessary, since there is currently far more gear than would be needed to fully harvest the largest runs the canneries can handle. Crutchfield and Pontecorvo (1969) give an excellent presentation of the economic arguments against unlimited entry in salmon fishing and provide a background to explain why the addition of more but superfluous gear in response to a price rise in raw fish would dissipate, and thus negate the potential net economic benefits from forecasting and optimum management. In essence, the additional, unnecessary manpower and investment in fishing vessels would represent a loss to other areas of the economy where they could have been employed productively.

The potential benefits thus far reported are those resulting from an increase in the average difference between gross cannery revenue and operating costs. One of the desirable results of forecasting was an increase in average harvest resulting from both a greater degree of industry preparedness for otherwise unexpectedly large runs and greater precision of management of the stocks. A forecast of the entire run increased the harvest by about 50 000 cases of canned salmon or 750 000 fish, and forecasts of separate stocks added further to the harvest of up to 200 000 cases, or 3 000 000 fish. Since fishermen receive over $1.00 per fish, forecasting could provide benefits approaching $3 000 000 to the fishermen in addition to those measured previously. This could be a net economic gain since little if any additional gear would be necessary to take the additional harvest.

The conclusion one reaches in evaluating forecasting, or any other useful fishery management tool, is that some form of fishing gear limitation and eventual reduction is required to fully take advantage of the economic benefits accruing from increased harvests. Thus, the ultimate evaluation of forecasting requires a comparison between a non-forecast and a forecast policy under the hypothetical situation of a limited, efficient, and optimum-sized fishing fleet. The optimum fleet is not necessarily that required to fully harvest the largest runs possible, but depends in a complex manner on fishing costs, the capacity and technology of the industry, and variability of the runs. Certainly the optimal amount of efficient fishing gear would be no more than the processing segment requires to fully supply it with fish at maximum capacity, and might be someting less than this. By including a fishing sector with stated input costs and estimated maximum fishing power of each boat, the simulation model was made suitable for estimating the optimal size of the fishing fleet with each forecast policy.

The fleet size was simply varied until the point of maximum net economic yield was found, where net economic yield was the sum of fishing sector net yield (total revenue from raw fish sales minus total fishing costs) and operating margin to the canneries (Table 5). With no forecast, a fleet of 300 boats maximized the average net yield, even though this small fleet did not maximize the harvest or the operating margin to the canneries. This is because it did not "pay", on the average, to keep a larger fleet around to harvest the occasional large runs. With a forecast of the total run, a fleet of 350 boats was optimal, and the net yield at this optimal point was about $1 200 000 more than at the optimal point with no forecast. With forecasts of separate runs, the optimal fleet was again 350 boats, and the maximum net yield averaged about $4 000 000 more than the maximum with only a forecast of the total run.

In summary, the value of forecasting would depend on the policy regarding amount of gear in the fishery. If there was no limitation or further entry, much of the forecast benefits would be dissipated by entry of superfluous gear to the fishery. If a freeze was placed on the amount of gear, the benefits from highly accurate forecasts could be substantial and in the following neighbourhood:

Table 5. Performance of the Bristol Bay simulation model with fishing fleets of varying sizes; figures are averages for three 100-year replicates

Number of two-man gill net boats	Total net[1] yield (millions of dollars)	Net yield to the fishing sector (millions of dollars)	Cannery operating margin (millions of dollars)	Total pack (millions of cases)
	No forecast; investment according to 4-year cycle			
150	9.949	6.135	3.813	.466
200	10.617	6.474	4.143	.508
250	10.642	6.440	4.202	.516
300	10.728	6.426	4.302	.547
350	10.517	6.189	4.328	.552
400	10.253	5.915	4.332	.555
450	9.923	5.591	4.332	.555
500	9.718	5.348	4.369	.560
800	8.161	3.696	4.465	.575
1 200	5.781	1.256	4.526	.580
2 000	.849	-3.170	4.559	.585
	Forecast of total run with ±10 per cent error			
150	10.389	6.311	4.078	.478
200	11.322	6.786	4.536	.530
250	11.570	6.868	4.702	.556
300	11.849	7.000	4.849	.585
350	11.920	6.997	4.924	.606
400	11.729	6.784	4.946	.612
450	11.534	6.561	4.974	.619
500	11.360	6.342	5.019	.625
800	9.844	4.722	5.122	.643
1 200	7.396	2.241	5.155	.645
2 000	2.402	-2.768	5.170	.647
	Forecast of separate runs with ±10 per cent error			
150	11.336	7.024	4.311	.520
200	13.209	8.090	5.118	.615
250	14.542	8.923	5.619	.691
300	15.735	9.743	5.993	.766
350	15.966	9.943	6.023	.801
400	15.936	9.866	6.070	.809
450	15.677	9.597	6.080	.818
500	15.484	9.369	6.116	.824
800	14.257	7.943	6.314	.855
1 200	11.814	5.507	6.357	.859
2 000	6.903	.521	6.382	.864

1/ This is not net yield strictly speaking since fixed costs in the canning industry have not been subtracted. It is the sum of the net yield to the fishing sector and the operating margin to the processing sector.

	Forecast of total run	Forecast of separate runs
Potential to the fishermen	$ 900 000	$4 200 000
Potential to the canneries	600 000	1 800 000
Total	$1 500 000	$6 000 000

If there was a reduction in the present amount of gear to the point of optimum fleet size, not merely a freeze on further entry, the forecasts alone would be worth slightly less, but the net yield from the fishery would of course be far greater than with a fleet size of the present 2 000 or more vessels.

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